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Bycatch mortality of endangered coho salmon: impacts, solutions, and aboriginal perspectives

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Abstract. We used biotelemetry and human dimensions surveys to explore potential solutions to migration mortality of an endangered population of coho salmon caught as bycatch in an aboriginal beach seine fishery. From 2009 to 2011, 182 wild coho salmon caught as bycatch in the lower Fraser River (Canada) were radio-tagged and tracked as they attempted to complete their migrations to natal spawning areas over 300 km upstream. Failure to survive to reach terminal radio receiving stations averaged 39% over three years. This mortality estimate is low compared to those obtained from telemetry studies on other salmon fisheries in the Fraser River. However, this value is markedly higher than the mortality estimate currently used to manage the fishery's impact. It is also in contrast to the perceptions of the majority of aboriginal fishers, who did not think survival of coho salmon is affected by capture and release from their fishery. Increased probability of survival was associated with lower reflex impairment, which is consistent with previous findings. Reflex impairment was positively correlated with entanglement time, suggesting that greater efforts by the fishers to release bycatch from their nets quickly would minimize post-release mortality. Survey responses by aboriginal fishers also suggested that they are receptive to employing new bycatch handling methods if they are shown to increase post-release survival. However, attempts to facilitate revival of a subset of captured fish using cylindrical in-river recovery bags did not improve migration success. Fisheries managers could use the new information from this study to better quantify impacts and evaluate different harvest options. Since aboriginal fishers were receptive to using alternate handling methods, efforts to improve knowledge on minimizing reflex impairment through reductions in handling time could help increase bycatch survival. Such a direct integration of social science and applied ecology is a novel approach to understanding conservation issues that can better inform meaningful actions to promote species recovery.

Key words: biodiversity conservation; by-catch; conservation social science; discards; fisheries management; integrative science; Oncorhynchus kisutch; *Pacific salmon; radio telemetry; RAMP (Reflex Action Mortality Predictor).*

Introduction

There are numerous examples in the literature of conservation scientists calling for an integration of the social sciences into biological research, and for the need to bridge the gap between science and conservation action (e.g., Campbell 2005, Fox et al. 2006, Lowe et al. 2009, Sutherland et al. 2009, Margles et al. 2010). Yet research papers that include and integrate both sociological and biological data remain uncommon, despite their obvious potential to develop more "actionable" science (Cook et al. 2013). There are some examples. Irvine et al. (2009) interviewed managers of red deer *Cervus elaphus* populations, and combined their perspectives with scientific data to build habitat use models for the species. Interview approaches alone have been used to build models, such as for assessing threats to endangered sea turtles (Donlan et al. 2010). Donaldson et al. (2013) demonstrated that comparative physiology and radio telemetry could be combined with human dimensions surveys to address revival strategies for angled and released sockeye salmon *Oncorhynchus nerka*. Given that application of the best science can be improved with stakeholder input, incorporating

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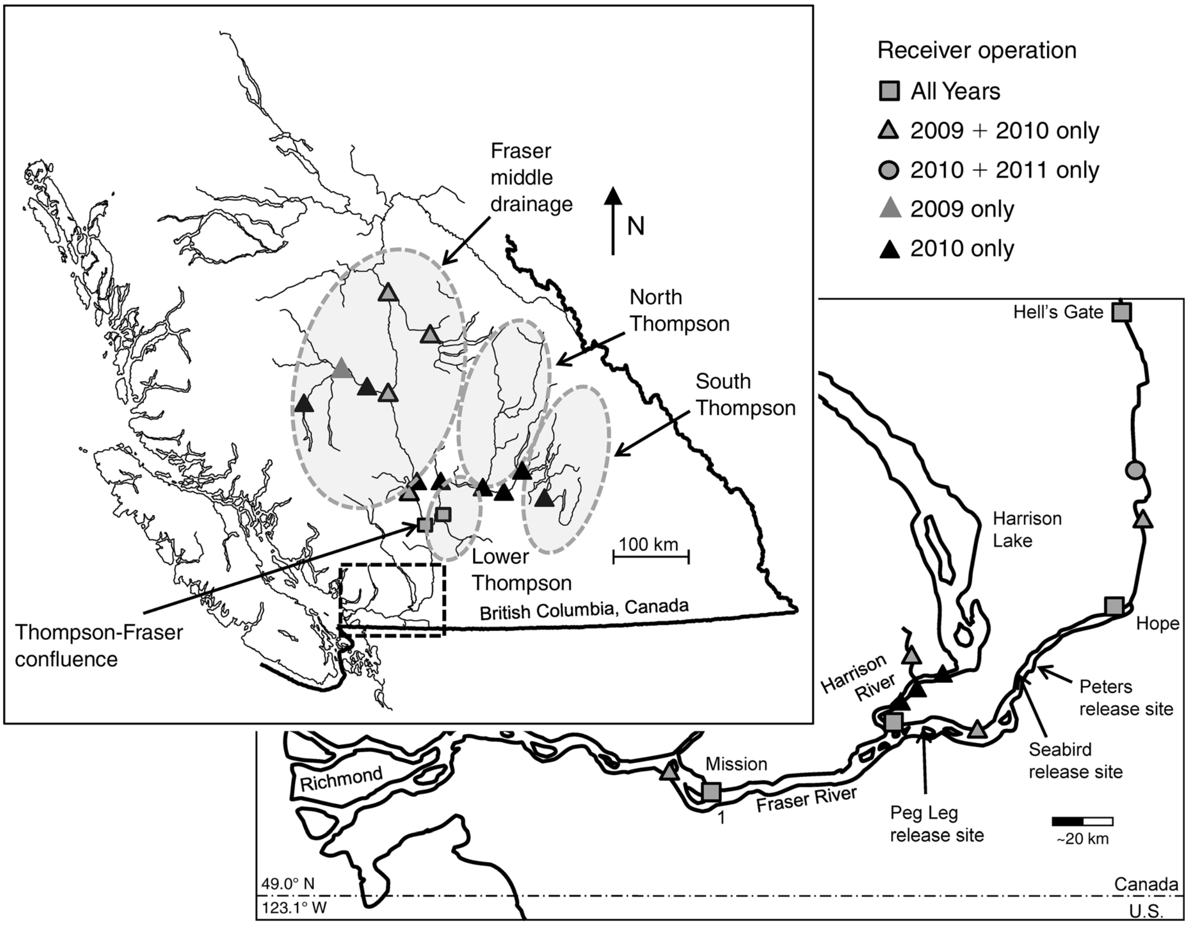

Fig. 1. Fraser River watershed map with locations of radio receivers used in different years and the locations of the three main capture/release sites (Peg Leg, Seabird, and Peters). The spawning areas of the four main interior Fraser coho salmon populations are indicated and circled by gray dashed lines. (Not circled: the Fraser canyon population, which comprises only one DNA-identified spawning tributary, the Nahatlatch River ~30 river kilometers (rkm) upstream of Hell's Gate [Beacham et al. 2011].)

human dimensions data into conservation science is a natural fit.

Pacific salmon *Oncorhynchus* spp. are among the most well-studied wild animals. Their contribution to human culture, economies, and the functioning of ecosystems, coupled with the fact that many populations are in decline, means that they receive enormous research attention from conservation scientists (Scarnecchia 1988, Gende et al. 2002). Their importance as a natural resource and the complexity of socio-political considerations in how they are managed (Scarnecchia 1988, Lackey 1999) make this a particularly fruitful area for integrative research. In the Fraser River, British Columbia, Canada, the fishery for Pacific salmon is complex, involving different user groups (aboriginal, recreational, and commercial) that target several species comprising hundreds of unique populations, many of which migrate upriver toward spawning grounds at the same time. Inherent in managing these fisheries is the objective that diversity be maintained, both within and among species (DFO 2005). Interior Fraser River coho salmon (*O. kisutch* that spawn in tributaries of the Fraser River upstream of Hell's Gate; Fig. 1) have received particular attention in recent years owing to their listing as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This population of coho salmon experienced a ~60% population decline during the 1990s, attributed mainly to overfishing and habitat alteration (Bradford and Irvine 2000). Directed harvest of wild coho salmon in British Columbia was closed in 1999 and the population has since stabilized at 20 000–30 000 returning adults, an incomplete recovery to pre-1990s abundance (R. Bailey, DFO, *personal communication*). To ensure that bycatch mortality is not limiting recovery, in-river fisheries for other species have been significantly curtailed at the time of year that interior Fraser coho begin migrating through the river (IFCRT 2006). There have been some exceptions to this management strategy, including permitting aboriginal groups to conduct beach seine fisheries in the lower Fraser River targeting pink *O. gorbuscha*, chum *O. keta*, or sockeye salmon. Beach seines are thought to enable the live release of bycatch with higher subsequent survival than alternative gear such as gill nets. Regulations for the beach seine fishery state that fishers must release all wild coho salmon that are alive, with an inherent assumption that most of these fish will survive, continue their migration, and ultimately spawn. The agency responsible for managing this fishery (Fisheries and Oceans Canada; DFO) applies a 5% mortality rate to coho salmon bycatch for the purposes of accounting for fishing mortality and meeting spawning escapement targets (IFMP; DFO 2011). However, there is very little empirical evidence to inform estimates of beach seine bycatch mortality. Factors affecting mortality remain poorly understood, limiting the ability of fisheries to implement practices that can minimize mortality.

When a fish is captured in a fishery, it experiences a suite of physiological disturbances (Farrell et al. 2001, Davis 2002) and typically, some degree of injury (Chopin and Arimoto 1995). Although the proximate causes of post-release bycatch mortality are not well understood in fishes (Wood et al. 1983), certain components of the capture experience are likely more harmful than others. For example, crowding, hypoxia, air exposure, and exhaustive exercise are all thought to negatively affect fish (Ferguson and Tufts 1992, Davis 2002, Marçalo et al. 2006). Bycatch research can be used to identify specific components of a capture stressor that most heavily influence mortality, information which can lead to improved capture or handling practices (Davis 2002). The magnitude and duration of the capture stressor can influence physiological recovery time (Donaldson et al. 2010), suggesting that minimizing capture stress is important. In addition, there are techniques that can facilitate metabolic recovery of fish, and in some cases, improve post-release survival (Milligan et al. 2000, Farrell et al. 2001). For example, provision of a dark recovery environment that is free from predators and provides high flow across the gills can promote re-oxygenation of tissues, re-invigorating fish before release (Farrell et al. 2001). Recent work in a sockeye salmon recreational fishery has shown that specially designed fish "recovery bags" (Donaldson et al. 2013) could be used to increase survival in some contexts.

This three-year study aimed to quantify capture experience for individual fish and use radio telemetry to assess survival. Combined with interviews of the aboriginal fishers taking part in the fishery, this study used an all-encompassing approach to provide results relevant to resource managers. There were three general objectives: (1) estimate immediate (i.e., at the time of capture) and post-release bycatch mortality for wild coho salmon caught in beach seines, (2) identify factors associated with mortality, and (3) assess potential ways to manage or reduce mortality. Given that a reflex impairment index can be used to predict delayed mortality in this fishery (Raby et al. 2012), we also explored correlates of reflex impairment. For objectives 2 and 3, we hoped to identify specific aspects of the capture experience that were most associated with mortality (e.g., crowding time) and evaluate whether cylindrical in-river fish "recovery bags" could be used to promote survival. Semi-structured interviews were used to understand fisher perspectives on issues relating to each of our objectives.

Materials and Methods

Study area and fish capture

This study took place in the Fraser River watershed (British Columbia, Canada). Data collection occurred over three years (2009–2011) during openings of the aboriginal beach seine fisheries. The fishery was targeting pink salmon in 2009 and 2011, and sockeye salmon in 2010. In each case, Fraser River coho salmon caught as bycatch were en route upstream towards their natal streams to spawn. We attended the fishery to collect data every day it was open in each year; 21–23 September in 2009, 15–17 September in 2010, and 17–19, 22, and 24 September in 2011. The mean daily river temperature, measured at a temperature-monitoring station upstream of Hope (Fig. 1), was 15.88°C (range, 15.76°–16.08°C) on the fishing days in 2009, 15.12°C in 2010 (15.07°–15.18°C), and 15.32°C in 2011 (14.85°–15.59°C).

We worked with multiple fishing crews at five different locations (some fishing sites had two or more fishing crews operating adjacent to each other). Almost all of the data collection occurred at three sites; Peg Leg, Seabird, and Peters (Fig. 1), which were 108, 129, and 131 river kilometers (rkm), respectively, upstream of the river mouth. Those sites and crews were chosen based on accessibility, the number of crews, and the size of catches. The two other sites were Mountain Bar (just downstream of Peg Leg; 8 fish tagged) and a location halfway between Peg Leg and Seabird (2 fish tagged; Fig. 1).

The fishing crews used beach seines that were 90 m long $\times$ 9 m deep $\times$ 5 cm diamond stretch mesh. Nets were pulled out from the riverbank using powerboats with one end anchored on shore and were allowed to drift downstream for $\sim$30–60 s, then pulled by the boat in an arc to a downstream point on shore (total time $\sim$5 minutes), before being pulled in by hand or with a truck until fish were crowded into shallow water ($<$0.5 m deep) for sorting (Fig. 2). Attempts at locating and releasing bycatch varied among crews, but in most cases crews spent 1–3 minutes searching for bycatch immediately after the net was in shallow water prior to collecting their target species. When coho salmon were found by the fishing crew, they were given to us for tagging and biopsy (details follow) rather than released directly to the river. Entanglement time was calculated for each fish as the time between the net being pulled to shore and the fish being released from the net. For each set, we also obtained the total number of adult salmon caught from a member of the fishing crew whose duty

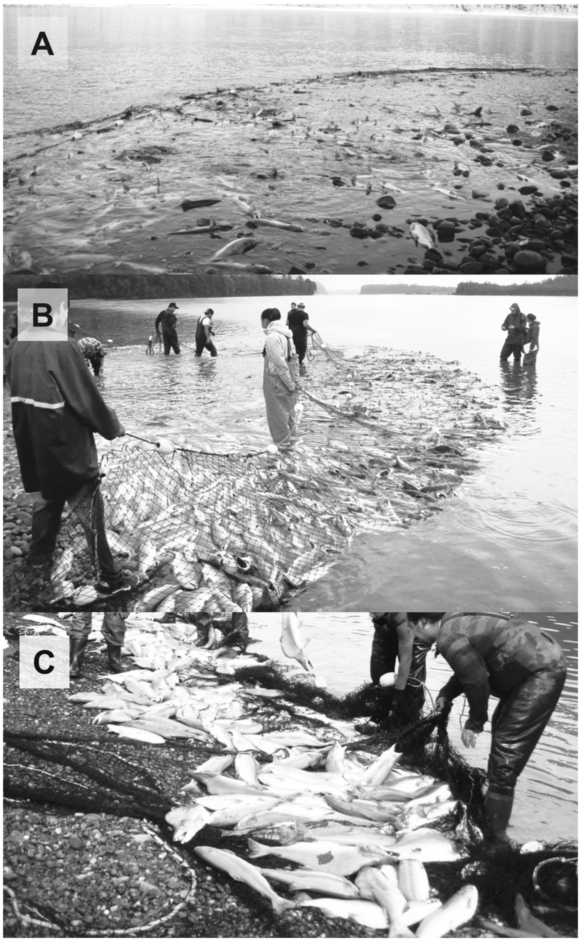

FIG. 2. Photographs showing different ways in which the aboriginal fishing crews pulled their nets into shore for sorting, during which "entanglement time" was recorded for individual coho salmon caught as bycatch. Photos show (A) a typical set, (B) a very large set with high crowding that required hours to sort through, and (C) a smaller set that was pulled entirely onto shore for sorting.

was to enumerate the catch. For some sets only the number of females was recorded (only females were being retained); for such sets we estimated the total catch by assuming a 50:50 sex ratio.

Fish sampling and tagging

Upon removal from the seine, coho salmon were immediately placed in individual fish holding bags for tagging, biopsy, and measurements. The bags were cylindrical (1 m long × 30 cm diameter) and made of Hypalon (thick synthetic rubber; DuPont Performance Elastomers, Beaumont, Texas, USA) with fine mesh ends that allowed river water to flow through. Radio transmitters were gastrically inserted, a rapid (<10 s) tagging method with no anesthesia that has been validated and used extensively in Fraser River salmon (e.g., Cooke et al. 2005, English et al. 2005, Martins et al. 2011, Wilson et al. 2013). We used two models of individually coded radio transmitters that were functionally identical with the same transmission frequencies, dimensions (16 mm diameter × 46 mm long, with 460 mm long antenna), and mass (17 g in air, 7 g in water [Pisces 5, Sigma-Eight, Newmarket, Ontario, Canada; and MCFT-3A-3 V, Lotek Wireless, Newmarket, Ontario, Canada]).

Once tagged, each fish was measured for fork length (FL, nearest cm) and any apparent injuries were noted. A ~0.56-g piece of adipose fin tissue was removed from each fish using a hole punch, and stored in 95% ethanol for DNA analyses. Finally, we conducted a rapid (<20 s) assessment of the presence or absence of five simple animal reflexes (identical to Donaldson et al. 2012, Raby et al. 2012, 2013, Brownscombe et al. 2013, Cooke et al. 2014). This method, called RAMP ("Reflex Action Mortality Predictor"), was validated and summarized using data from 2009 (Raby et al. 2012). The first reflex assessed was tail grab, considered impaired if the salmon failed to exhibit a burst swim response after having its tail grabbed by the handler (up to three attempts, or grabs). For tail grab, the fish was underwater in the bag and otherwise not held or impeded from attempting to swim. Next, the fish was held around the middle of its body using two hands (forming a ring with the index fingers and thumbs) and lifted into the air, just above the water's surface; this reflex (body flex) was assessed as impaired if the fish did not attempt to vigorously struggle free of the handler within 3 s. Simultaneously, we assessed "head complex," whether the fish exhibited a regular pattern of ventilation. Vestibular-ocular response (VOR) was also assessed; whether the fish's eye rolled to track the handler and maintain level pitch when the handler rolled the fish along its lengthwise axis (a.k.a. ocular counter-rolling). Finally, upon release, orientation was assessed by releasing the fish upside down in the water column just below the surface; this reflex was recorded as impaired if the salmon failed to right itself within 3 s. The reflex responses were cumulated into a RAMP score that represented a proportion of reflexes that were impaired, with a higher score thus indicating a fish in poorer condition, which is less likely to survive (Davis 2010, Raby et al. 2012). Following tagging, measurements, and the reflex assessment, coho salmon were released to resume their migration towards spawning areas (except for fish exposed to the recovery bag treatment).

Beginning in 2010, tagged coho salmon were chosen at random for an experimental treatment to evaluate whether a cylindrical recovery bag could be used to increase post-release survival. The bags that were used for facilitated recovery (Fig. 3) were narrower than those used for tagging (20 cm diameter × 1 m length) and had much larger mesh (4 cm diameter rigid diamond mesh) to maximize the flow of river water through the bag along its longitudinal axis. Once each fish was transferred into the recovery bag facing into the current, the lengthwise zipper along the top was closed and the bag

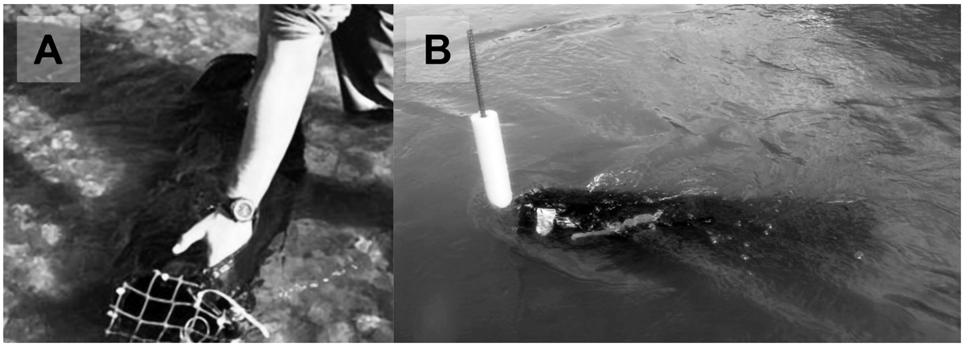

FIG. 3. Images showing (A) the fish recovery bag open at the water's surface prior to having a fish inserted for (B) a 30-minute revival period in the river current with the bag attached to a reinforcing bar driven into the riverbed. (Photo credit for A is Jude Isabella.)

was attached to a 1.5 m long reinforcing bar that had been driven into the riverbed (Fig. 3B). The duration of the treatment was 30 minutes, after which time the zipper was opened with the bag fully submerged and the fish encouraged to swim out of the top of the bag. Since fish were captured and tagged at different sites, the water speed passing through the recovery bag varied among fish. However, the recovery bag treatment occurred only at three tagging sites (Peg Leg, Seabird, Peters), and we consistently used the same location at each site. The mean water speeds where the recovery bags were placed were ~0.5 m/s at Peg Leg, ~0.2 m/s at Seabird, and ~0.7 m/s at Peters.

Cumulatively, we radio-tagged and tracked 182 coho salmon: 50 in 2009, 53 in 2010, and 79 in 2011. In each year, all coho salmon were tagged until our supply of radio transmitters was exhausted—in total we handled 295 coho salmon. Fish that did not receive transmitters were otherwise processed in the same way, with the primary goal being to collect additional RAMP and entanglement time data. Of the 182 that were tagged, 64 were exposed to the recovery bag treatment; roughly half of the 132 fish we tagged over 2010 and 2011 (no recovery bag treatment in 2009). Most of the data collection in 2010 and 2011 occurred at Peg Leg, and thus most of the recovery bag treatments (43 of 64). In 2011, we collected additional data on bycatch condition (e.g., RAMP, fork length, entanglement time) from 53 individuals that were not tagged. Also in 2011, we opportunistically used a handheld meter (CellOx 325, WTW, Weilheim, Germany) to monitor oxygen depletion over time in beached seines. This was done to estimate the extent to which localized DO depletion can occur in crowded seines during sorting.

Population identification

There are five genetically unique and geographically distinct populations of coho salmon within the interior Fraser River population complex (see Fig. 1 and Beacham et al. 2011). Adipose fin tissue collected from each individual was used for stream-origin identification via analysis of variation of 17 microsatellite loci (Beacham et al. 2011). Fish were identified to individual spawning streams, but spawning stream fidelity within subpopulations can be low in some years if low flows necessitate finding an alternate spawning site (R. Bailey, DFO, *personal communication*). Thus, for our analyses fish were simply grouped into their populations: Fraser canyon, Fraser middle drainage, lower Thompson River, North Thompson River, and South Thompson River (Fig. 1, Table 1). Coho salmon tagged in this study also belonged to three additional populations that were not from the interior Fraser River watershed: Birkenhead River, Chilliwack River, and the lower Fraser drainage (Table 1). Identification of population origin facilitated accurate determination of whether individuals successfully migrated towards their natal subwatersheds, beyond terminal radio receivers.

Telemetry tracking

Radio-tagged coho salmon were tracked using an array of radio receiver stations installed at strategic points in the watershed (Fig. 1); these methods were previously used to assess survival of Fraser River salmon (e.g., English et al. 2005, Cooke et al. 2006, Donaldson et al. 2011, 2013, Nguyen et al. 2014). The receiver array differed in each year, but key receivers were present at the same locales each year (e.g., Hope, Hell's Gate, Thompson–Fraser confluence). We considered coho salmon as migratory "survivors" if they were detected at the upstream-most receiver stations en route to spawning areas. In eight instances (among all 182 fish) there was clear evidence of straying, whereby fish migrated to terminal spawning areas to which they were not DNA-identified (e.g., into the South Thompson watershed rather than the North Thompson), in some cases undergoing lengthier upstream migrations than if they had migrated to their natal stream. Those fish were assessed as survivors. Distances from terminal receivers to actual spawning sites varied depending on spawning location (~5–300+ rkm; Fig. 1). We also quantified shorter-term, two-day survival. Detection efficiency was variable among receivers and years (range = 24–100%), but was generally high, particularly at the key receivers

TABLE 1. Population (stock) proportions and individual stream IDs of coho salmon captured in the study from 2009 to 2011, determined via analysis of microsatellite variation in DNA ($N = 223$ [see Beacham et al. 2011]).

Interior Fraser coho population, N (%)	Actual percentage of overall population group (%)	Fork length (cm, mean ± SE)	Post-release survival estimate (%)	Stream origin (N individuals)
North Thompson River, $N = 86$, (41)	35	61 ± 0.7	67	Pig Channel (37), Lemieux Creek (20), Louis Creek (8), Birch Island (7), Fennell River (6), Reg Christie Creek (5), Dunn Creek (2), Mann Creek (1)
Lower Thompson River, $N = 41$, (20)	23	61 ± 0.9	73.6	Coldwater River (28), Spius Creek (12), Bonaparte River (1)
South Thompson River, $N = 38$, (18)	21	62 ± 0.8	58	Eagle River (20), Harbour Creek (7), Momee Creek (6), Bessette Creek (3), Salmon River (3), Wap Creek (2)
Fraser River middle drainage, $N = 37$, (18)	13	61 ± 0.9	52	Bridge River (22), McKinley Creek (13), Gates Creek (2)
Fraser River canyon, $N = 7$, (3)	8	67 ± 2.4	71	Nahatlatch River (7)
Birkenhead River, $N = 6$		67 ± 3.8	67	Birkenhead River (6)
Fraser River lower drainage, $N = 4$		71 ± 2.2	75	Chehalis River (4)
Chilliwack River, $N = 1$		67	0	Chilliwack River (1)

Notes: These samples include fish tagged and released with transmitters and additional fish sampled for DNA (mostly blood-sampled fish from 2009; see Raby et al. 2012). All of these groups are part of the interior Fraser coho group except for the bottom three populations, which split off the Fraser River main stem downstream of Hell's Gate. "Actual percentage of overall population group" refers to the true percentage of the entire interior Fraser River coho salmon group represented by each population, based on DFO spawning ground stock assessment data for the years 2009–2011 (R. Bailey, DFO, *personal communication*). Post-release survival was not significantly different among populations ($\chi^2 = 1.39$, df = 5, P = 0.99).

(i.e., Thompson–Fraser rivers confluence) and at many of those used as "terminal" points for assigning survivorship. For example, detection efficiency at the Thompson–Fraser confluence was 100% in 2009, 96.7% in 2010, and 85.4 % in 2011. Detection efficiency was 100% at Hell's Gate in 2009 and 2010, and 56.8% in 2011. Detection efficiencies were assessed by dividing the number of fish detected on a receiver by the total number known to have passed that receiver, confirmed either by detection at subsequent receivers, by mobile tracking efforts, or by tag recaptures that were reported. Detection efficiency estimates were therefore inherently less robust for the upstream-most receivers, and in some cases, unknown for a given terminal receiver in a given year. In general, very little mortality was apparent in upper watersheds (beyond the Thompson–Fraser confluence) such that non-detection at terminal receivers was uncommon for fish that had reached the next most upstream receiver. Among all 182 fish, there were six individuals assigned as mortalities based on non-detection at a terminal receiver whose efficiency was unknown in that year (two in 2010, four 2011), meaning that there was some uncertainty associated with final migratory success of those fish. Nevertheless, receivers in upper watersheds typically have good detection efficiency, because fish are generally moving through narrower and shallower waters as they approach spawning areas, thus reducing the likelihood of fish using deep-water locations that prevent them from being detected.

Data analysis and statistics

To determine what factors affected post-release survival (0 = died, 1 = survived), we used a forced-entry binary logistic regression with six predictor variables: entanglement time (s), total catch size (number of fish), air temperature, FL, use of revival bag treatment (0 = not used, 1 = used), and RAMP score. Air temperature was used in place of river temperature because it varied widely among study days, possibly affecting water temperatures in shallow streamside areas where entanglement occurred, whereas deeper river temperatures exhibited minimal variation where temperature monitoring stations were located. Differences in survival among populations, years, and capture locales were assessed for significance using Pearson's chi-square test. To look for associations between RAMP scores, handling time, and total catch, we used Spearman rank-order correlations. Confidence intervals for mortality rates were calculated to provide a measure of sampling error, and took the form of binomial confidence intervals, based simply on the number of mortalities and the total number of fish (using the Clopper-Pearson exact method, similar to Stokesbury et al. 2011). All statistical tests were conducted using R (v. 3.0.0). Tests were assessed as significant at $\alpha = 0.05$.

Human dimensions surveys

In 2011, we conducted face-to-face interviews with aboriginal fishers and members involved with the aboriginal fishing process, which included crew monitors, fish buyers, and buying employees ($N = 111$). We included the latter groups (<10% of interviewees) because they were also aboriginal and most had directly participated in this harvest fishery in the past as fishing crew members or had extensive exposure to beach seining through their role in the fishery. Moreover, buyers and monitors are highly involved with the fishing process, are knowledgeable about fishing methods and locations, and can potentially influence fisheries policy. Participants were chosen opportunistically due to logistical limitations (i.e., access to fishing sites), and timing of when fishing crews were on breaks from fishing. We aimed to interview at least 50% of the members of each crew, including the crew chief, and to interview all crews present at a given site. We interviewed members of ~30% of the fishing crews who participated in the beach seine fishery in 2011 (Karen Burnett, DFO, *personal communication*). Beach seine crews consisted of 11 individuals on average (range = 8–13). Fewer than 5% of those approached declined to take part in the interview. Seventy-two (72) of 111 interviews were conducted streamside during the aboriginal economic opportunity beach seine fishery in the lower Fraser River. The remaining 39 interviews were opportunistically conducted during an aboriginal economic opportunity gillnet fishery (targeting sockeye salmon) that occurred a month earlier (on 24 and 25 August 2011) in the lower Fraser River watershed. Because questions No. 1–4 (see the following paragraph) only pertained to the beach seine fishery, respondents in the gillnet fishery were only asked those questions if they stated that they also take part in the beach seine fishery, or have done so in the past (28 of 39).

The interviews were semi-structured, meaning that respondents could identify any additional topics, concerns, or ideas relating to coho bycatch during the interview. The interviews were used to address a number of research objectives, some of which are beyond the scope of this paper (see Nguyen et al. 2012). We used two separate interviews: one shorter questionnaire and a long-form questionnaire. The short questionnaires were a subset of the long questionnaire, and included the same closed-ended questions (data not presented here), while open-ended questions alternated among the following themes: participant perspectives on coho bycatch, perspectives about biotelemetry science, and thoughts on the fish recovery bag. The short questionnaire was intended to be for individuals that only had 5–10 minutes to spare, while effort was made to ensure all crew leaders participated in the long questionnaire. For individual questions, the number of responses was somewhat lower than the total number of interviewees (111, see Figs. 5–7) because alternating versions of the shorter questionnaire contained only a subset of the questions, or because a question was not applicable to the interviewee (e.g., if they were a fish buyer). We asked the following questions.

1) Do you think that beach seine capture has any effect on a coho's chance of successful migration or spawning?
2) What do you think causes the greatest stress for coho released from beach seines?
3) What suggestions do you have to increase the survival of coho bycatch?
4) If you knew that leaving the seine in knee-high water for sorting would increase the chance of survival for released fish, would you voluntarily do it?

The interviewees were then shown a fish recovery bag (those tested in this study), accompanied by an explanation of its purpose and use. They were then asked the following questions.

5) What are your thoughts on the recovery bag?
6) If research data show the recovery bag improves post-release survival for salmon, how likely would you be to use one on a voluntary basis?
7) Do you think the recovery methods and gear should be mandatory for reviving coho bycatch from seine capture?

All survey responses were coded according to emergent themes following standard qualitative protocol (Strauss 1987, Creswell 2009). We assessed for consistencies among codes (similar meanings or pointing to a basic idea), and revealed themes and categories reflecting fisher responses to the particular questions (Figs. 5–7). For example, clear "yes" or "no" answers were often provided, but responses were in some cases classified as "no-conditional" when responses were "no" with conditions or dependent on certain situations (e.g., coho salmon are not affected by capture *if* they are handled carefully). For further information on how responses were categorized and details of their meaning, see the Appendix. We did not conduct any statistical tests on resultant survey responses, noting the paper by Drury et al. (2011) that recommends the use of qualitative approaches to using social science data in conservation research.

TABLE 2. Observed mortality rates (%, and number, in parentheses) of coho salmon bycatch for each of the three study years and estimated cumulative mortality rates.

Year (*N* tagged) and estimates	Immediate mortality (%)	Post-release mortality (%)	
		48 hours	To upper watersheds
2009† (50)	5 (5 of 104)	6 (3 of 50)	26 (13 of 50)
2010 (53)	2 (1 of 55)	15 (8 of 53)	43 (23 of 53)
2011 (79)	2 (3 of 135)	23 (18 of 79)	37 (29 of 79)
Overall estimates	3 (9 of 295)	18.6 (55 of 295)	37.3 (110 of 295)
Final mortality rate estimate‡			39.3 (116 of 295)

Notes: Immediate mortality numbers were generated by direct observation of whether individual fish were alive when released from the net, whereas mortality estimates to 48 hours and to natal sub-watersheds were made using radio telemetry. The overall estimates are weighted and cumulative such that the post-release mortality estimates were applied to fish that were released alive but not tracked. Differences in post-release mortality among years were not statistically significant (Pearson's chi-square test: $\chi^2 = 1.29$, df = 2, $P = 0.53$). The binomial probability 95% confidence interval for the final overall mortality rate (39.3%) was 34–45%. For 48-hour mortality (18.6%) it was 14–24%.

† From Raby et al. 2012.

‡ Final mortality rate estimate if RAMP scores were used to predict fates of non-tagged fish.

RESULTS

Collectively, we handled 295 wild coho salmon, bycatch that was spread across 98 net sets and three study years. In those net sets, collectively, an estimated 54 790 adult salmon were caught, meaning that the coho salmon bycatch for those sets was ~0.5% of total catch. The real bycatch rate is somewhat lower, owing to the fact that we did not record any data for sets in which no bycatch occurred (~20–40% of all sets). The median total catch (number of adult salmon) for net sets from which coho salmon were tagged was estimated as 500 (range, 70–2000). All but eight of the coho salmon we tagged and tracked were DNA-identified as belonging to the interior Fraser River population complex (Table 1; note that no fish were excluded from the mortality estimate on the basis of population origin).

Among all the coho salmon we handled from 2009 to 2011, the mean fish size (FL) was 61.6 cm (median: 62 cm, range: 37–82 cm). Median entanglement in the beached seine was 3 min 20 s (mean, 6 min 32 s; range, 5 s–55 min, 58 s). The most frequently observed RAMP score was 0.4, an impairment level that was characterized 97% of the time by loss of the tail grab and body flex reflexes. There was an apparent immediate effect of the recovery bag on fish vitality: after 30 minutes in the recovery bag treatment, all fish were highly vigorous (i.e., RAMP score of zero).

Bycatch mortality

Of the 182 coho salmon we tagged, 65 (36%) failed to migrate past terminal radio receivers en route to spawning areas, and were thus classified as mortalities (Table 2). Adjusting our sampling effort ($N = 182$) to a binomial distribution provides a 95% confidence interval (CI) for post-release mortality of 29–43% (Stokesbury et al. 2011). Nine of the 295 coho salmon (3%) caught during the study were dead upon being pulled from the net (Table 2). The cumulative mortality rate was 37.3% (95% CI = 32–43% mortality). Using the probability of mortality associated with each RAMP score to predict migration success of the non-tagged fish that were released alive (rather than applying a blanket post-release mortality rate to those fish whose fates were unknown), the extrapolated total mortality estimate was 39.3% (Table 2; 95% CI = 34–45% mortality). There were no significant differences in post-release mortality among the four main capture locations ($\chi^2_{3,\,181} = 1.71$, *P*

TABLE 3. Regression coefficients (*B*, with standard error) and odds ratios (with 95% CIs) for each predictor variable included in the logistic regression model with post-release survival as the binary response variable (0 = unsuccessful migrant; 1 = successful migrant).

Predictor variable	*B* (SE)	Odds ratio	95% CI for odds ratio	
			Lower	Upper
Constant	1.19 (2.60)			
RAMP score	**−3.56*** (0.93)**	**0.03**	**0.004**	**0.16**
Use of revival bag	−0.33 (0.42)	0.72	0.31	1.65
Entanglement time	4.5×10^{-4} (5.1×10^{-4})	1.00	1.00	1.00
Total catch	-6.8×10^{-4} (5.3×10^{-4})	1.00	1.00	1.00
Air temperature	0.05 (0.06)	1.05	0.94	1.17
Fork length (cm)	-1.1×10^{-3} (0.03)	1.00	0.94	1.07

Note: Overall model $R^2 = 0.127$ (Hosmer-Lemeshow), 0.154 (Cox-Snell), 0.21 (Nagelkerke). Model $\chi^2(6) = 24.45$. Odds ratios of below 1 indicate a negative relationship with the response variable, whereas the opposite is true of odds ratios above 1. RAMP score (shown in boldface type) was the only significant predictor of survival ($P < 0.001$).

*** $P < 0.001$.

= 0.63) or among years ($\chi^2_{2,\,181}$ = 1.29, P = 0.53). Estimated population-specific differences in mortality were not significant (Table 1; chi-square test, $\chi^2 = 1.39$, df = 5, $P = 0.99$). Among all the variables we tested as predictors of mortality, none were significant except for RAMP score, whereby fish with higher RAMP scores (more impaired) were less likely to be successful migrants (Table 3, Fig. 4). Use of a revival bag did not influence post-release mortality ($P > 0.05$, Table 3).

Since some in-river mortality is natural, there is a need to attempt to differentiate mortality caused by the capture itself. To do so, RAMP scores can be used whereby coho salmon released with little or no reflex impairment (vigorous) are assumed to experience no post-release bycatch mortality. Using that conservative assumption, the post-release mortality rate for those fish can then be used as a baseline within the data set. Additional mortality above that baseline that occurs at higher levels of reflex impairment can then be assigned to the fishery (see Fig. 4). The "baseline" post-release mortality rate at zero reflex impairment was 23% (Fig. 4). Applying a net mortality rate above that baseline for higher RAMP scores to the total number of fish at those RAMP scores yields a new estimated proportion of fish that died as a result of the capture stress: 13.6% overall of those released alive (Fig. 4). Combined with immediate mortality, this conservative approach accrues a bycatch mortality rate of 16.6% (95% CI of 13–21%).

Entanglement time and total size of the catch were not predictive of survival, but they were associated with reflex impairment (i.e., RAMP score, itself predictive of survival). There was a small but significant positive correlation between entanglement time and RAMP score (r_s = 0.18, P = 0.03). Total catch was not significantly correlated with RAMP score ($r_s = 0.15$, P = 0.06), but total catch and entanglement time were strongly correlated (Pearson's $R = 0.64$, $P < 0.001$).

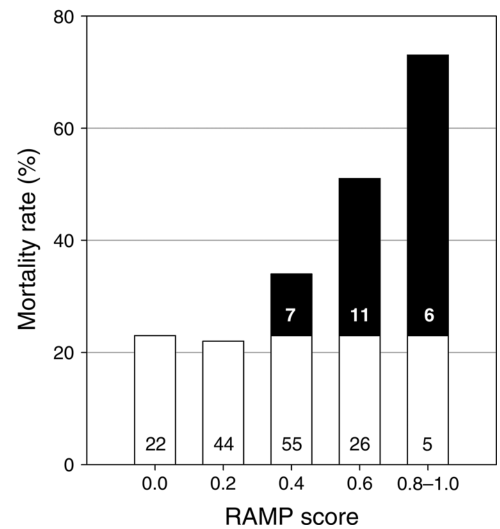

FIG. 4. Observed post-release mortality rates (whole bars) at each level of reflex impairment (RAMP score). The white sections of each bar represent a proposed "baseline" mortality rate within the data set, whereby only mortality that occurred above that level was assigned to the fishery. Based on this calculation, the numbers at the bottom of each bar represent the number of fish assigned as survivors of the capture event at each RAMP score, while the numbers in the black bars are the numbers of fish assigned as mortalities at each RAMP score by applying a net mortality rate (total mortality minus 23%) to the total number of fish with each RAMP score. For example, the net mortality rate used for the fish with RAMP scores of 0.6 was 28% (51% − 23% baseline), which was then applied to the total number of fish tagged at that RAMP score ($N = 37$). The two numbers within each bar add to the actual total number of fish released with transmitters at that RAMP score, but note that the total N in this figure is 176. Although 182 coho salmon were tagged and tracked, RAMP scores were not recorded for 6 individuals. Thus, this alternate post-release mortality rate of 13.6% comes from dividing the cumulative fishery mortalities indicated (24) by the total (176).

Human dimensions surveys

The majority of the participants of the beach seine fishery we surveyed stated that they thought beach seine capture does not or is not likely to affect a coho salmon's subsequent migration or spawning success (no effect, 41%; no effect under most conditions, 21%; total numbers of respondents provided in Fig. 5A). As such, only 12% of participants' responses were codified as a "yes," with a further 12% as a "conditional yes" (e.g., yes; stressful enough to reduce survival under certain scenarios). In a following question, many respondents identified crowding (23%), handling (19%), and air exposure (9%) as particularly stressful components of the capture experience (Fig. 5B). Fishers were then asked if they had any suggestions about how to increase the survival of coho salmon caught in their nets, and the most common response (26%) was to release fish quickly (Fig. 6A). Cumulatively, however, more respondents (35%) stated that nothing could be done (21%) or did not have an approach to propose (14%; Fig. 6A). When asked whether they would be likely to voluntarily leave the seine in knee-deep water for sorting (if it were shown to increase survival), 51% responded in the affirmative, while a further 26% stated that they already use this practice (Fig. 6B). Of respondents, 9% expressed concern that leaving the net in deeper water could compromise the safety of their crew.

We received positive feedback to the concept of the fish recovery bag. Of respondents, 47% (44 of 94) gave fully positive responses when briefed about its design and purpose and asked for their thoughts, with a further 17% providing conditionally positive responses (e.g., it would have to be shown to improve survival; Fig. 7A). Many fishers thought the use of a revival bag should be mandatory, without the qualifier that evidence would support its use (44%; Fig. 7B). However, responses were more positive to a proposal that recovery bag use be voluntary rather than mandatory, given scientific data to support use of recovery bags (Fig. 7C). A number of the conditionally positive responses arose from uncertainty about the monetary cost of the bags, and whether they would be provided or subsidized by management.

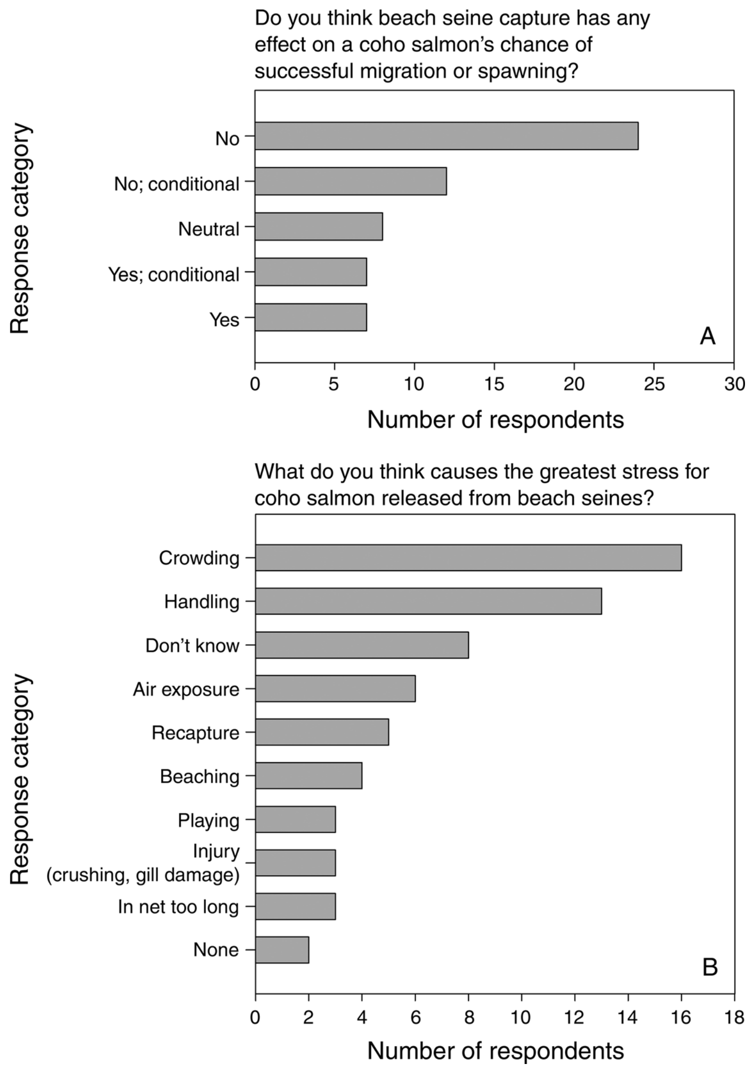

FIG. 5. Responses of aboriginal fishers in our human dimensions surveys to questions relating to coho salmon capture stress and mortality. For A there were 58 responses and for B, $N = 70$. Responses of individual fishers were coded into the response categories shown in the figure, and according to further details available in the Supplement.

DISCUSSION

We have provided an estimate of bycatch mortality for an endangered population of coho salmon captured in an aboriginal beach seine fishery, based on three years of tracking fish released from the fishery. In addition, we have evaluated whether altered capture and handling techniques (Fig. 2) or the use of a revival bag (Fig. 3) could reduce bycatch mortality. The inclusion of human dimensions data provides insight into the perspectives of the fishers on the impacts of, and solutions to, coho salmon bycatch in their fishery. This combined approach allows us to make recommendations to management that are informed by the resource users, who themselves can directly affect successful implementation of management strategies (e.g., rapid release of bycatch).

Bycatch mortality

The total observed mortality of 39%, inclusive of natural mortality, is relatively low when compared against similar studies on post-release survival for Fraser River salmon. For example, sockeye salmon caught by anglers experienced ~65–70% total mortality from release in the lower river to reach terminal radio receivers, while those released in parallel from a beach seine had a mortality rate of ~43–48% (Donaldson et al. 2011, 2013). Gillnets typically have higher post-release mortality, up to 70% within just 24–48 hours based on net pen holding studies (in the marine environment [Buchanan et al. 2002]); a 60% mortality rate is applied to gillnet bycatch by management to account for bycatch mortality in attempts to meet spawning abundance targets (DFO 2011). Thus, there appears to

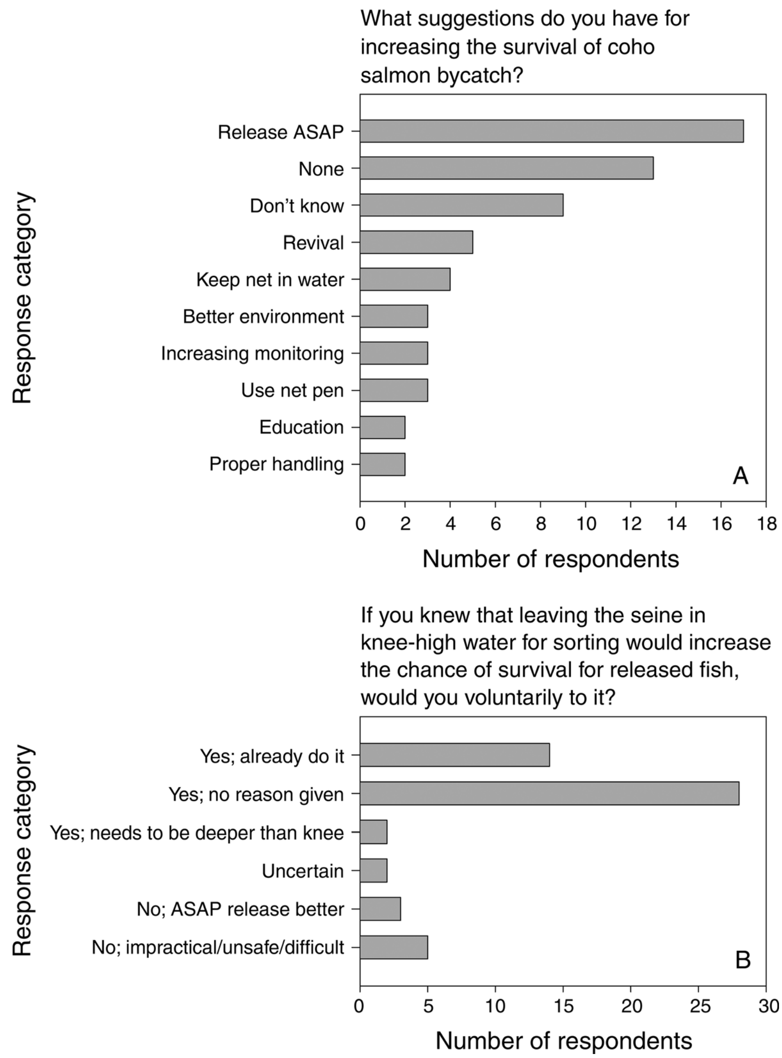

FIG. 6. Responses of aboriginal fishers in our human dimensions surveys to questions relating to ways to improve the survival of coho salmon bycatch in the beach seine fishery. Responses of individual fishers for both questions were coded into the response categories shown in the figure, and according to details available in the Supplement. There were 63 responses for question A. For B, $N = 54$.

be consistent evidence that beach seine capture results in the lowest post-release mortality for Fraser River salmon, particularly when using the more holistic approach of examining long-term mortality.

Not all observed mortality (39%) can be attributed to beach seine capture, as there is a component of natural en route mortality that we have no rigorous way of distinguishing. To account for impacts on numbers of salmon reaching spawning areas (termed escapement), DFO typically apply mortality rates to bycatch that are based on 24- or 48-hour post-capture net pen holding studies. Net pen studies can underestimate mortality because of possible synergies between capture stress and predation risk (Rogers et al. 2014), but do have the advantage that very little of any observed mortality is likely to be natural because of the small time window. Immediate and short-term (48-hour) mortality (combined) was estimated to be 18.6% in the present study (95% CI of 14–24%). An alternate approach to calculating a bycatch mortality rate that attempts to distinguish bycatch from natural mortality, is to use RAMP scores and their mortality rates at each level of impairment, and assume negligible bycatch mortality for the fish that were least impacted (vigorous at release). That approach (Fig. 4) yields a bycatch mortality rate of 17% (rounded from 16.6%). The remaining mortality (39 – 17% = 22%) could in such a case partly be attributed to a combination of natural migration failure, unreported fisheries removals, and the unknown long-term effects of the transmitter. Although we have no true control for the mortality we observed, this approach (Fig. 4) uses low RAMP score fish within our data set as comparative controls. The "control" mortality rate within the data set was 23%, from release to upper watersheds. For coho

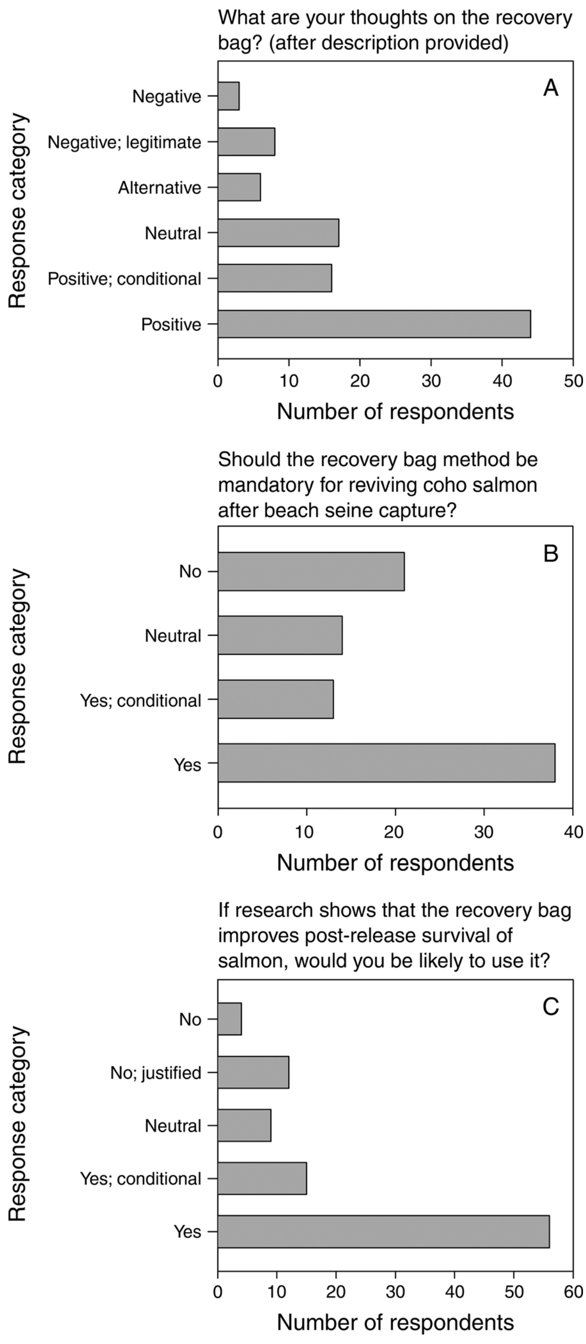

FIG. 7. Responses of aboriginal fishers in our human dimensions surveys to questions relating to the use of fish recovery bags for coho salmon bycatch in the beach seine fishery. Prior to asking questions A ($N = 94$ responses), B ($N = 96$), and C ($N = 86$), the interviewees were shown a recovery bag, and its purpose and use were explained to them. Responses of individual fishers were coded into the response categories shown in the figure, and according to details available in the Supplement.

salmon, high uncertainty exists about natural in-river mortality, but available data for Thompson River sockeye salmon stocks with similar migration timing show that natural mortality ranges from 8% to 20% from Mission (Fig. 1) to spawning areas (English et al. 2005, Martins et al. 2011).

True control mortality rates are often unknown in post-release mortality studies; every method of estimating mortality has limitations. Short-term captivity is the most common method (e.g., using a net pen) of estimating post-release mortality (Rogers et al. 2014), but this method fails to expose fish to the challenges of upstream migration and imposes severe chronic confinement stress (cortisol elevation) in wild Pacific salmon (Donaldson et al. 2011). The best alternative to captivity is to use biotelemetry (Donaldson et al. 2008), but most biotelemetry applications involve intracoelomic implantation via surgery or external attachment of a transmitter, with the latter typically requiring piercing the dorsal musculature to attach a tag that creates external drag (e.g., "backpack" attachment [see Colotelo et al. 2012]). The gastric tagging method we used is among the most rapid and least injurious tagging methods available in fisheries science: it involved a <1% tag burden (by mass), a rapid <10 s procedure with no injury or anesthetic, and created minimal hydrodynamic drag. This tagging procedure has been widely used in Fraser River salmon (Cooke et al. 2008, Martins et al. 2011) and, to some extent, validated as benign (Cooke et al. 2005, English et al. 2005, Wilson et al. 2013). The other components of our handling procedure were similarly rapid; the length measurement, DNA biopsy, and RAMP assessment each required <20 s to complete, and instances of air exposure (e.g., for assessing certain reflexes) were very brief (~5 s). Although blood biopsy has been commonly included in past biotelemetry studies on the Fraser River as a means of assessing stress, exhaustion, and identifying sex (e.g., Cooke et al. 2005), we avoided using it here to allay concerns of managers that it could affect mortality, despite evidence to the contrary (Cooke et al. 2005; G. D. Raby, *unpublished data*). Nevertheless, it would be nearly impossible to empirically test the independent or synergistic effects of different components of researcher handling on delayed mortality in the context of a real fishery. Although the length of research handling time was no different between fish that died and those that migrated successfully (Raby et al. 2012), the potential for our handling and tagging to add to mortality remains an area of some uncertainty. It is for that reason that we offer a conservative approach for assigning mortality to the fishery for management purposes (Fig. 4).

As with any mortality estimate, uncontrolled factors undoubtedly affect its accuracy and it is impossible to quantify this error. Reporting rates for radio-tag recaptures in the Fraser River are quite good in the recreational angling community, but the First Nations fishery has limited knowledge of the tag return-and-reward program in spite of its existence for ~10 years (Nguyen et al. 2012). In some cases, there were multiple beach seine crews directly upstream of where we were releasing tagged coho salmon, increasing the likelihood of recapture. Our interactions with many crews during the fishery will likely have increased awareness, but there may nevertheless have been some incidents of fish being recaptured and released after removal of the radio transmitter, and this would have mainly had the effect of increasing our 48-hour mortality rate. Some fish may have died because of capture despite being vigorous at release (e.g., at RAMP scores of 0 or 0.2; see Fig. 4), resulting in an imperfect relationship between RAMP and mortality. Assuming that is the case, the baseline mortality rate we used (23%) in calculating our "alternate" mortality rate of 17% would be an overestimate, with the true mortality caused by the fishery thus being higher than 17%. In addition, our receiver array did not extend all the way to spawning grounds, and it was not possible to verify spawning success. Latent capture-mediated disease-induced mortality likely occurs in fish (Lupes et al. 2006), though little is known about the potential for this to occur in any real fishery. In sockeye salmon, gillnet injuries can cause latent spawning failure for fish that reach spawning grounds because of their effect on reproductive physiology (Baker and Schindler 2009, Baker et al. 2013). Most importantly, observer effects, a well-known limitation to bycatch research (Benoit and Allard 2009), may have been a factor. All crews we worked with were clearly aware of our desire to radio-tag coho salmon, and spent a concerted 1–3 minutes attempting to locate bycatch upon landing of the net, prior to focusing on sorting their target catch. If such efforts are not typically made, entanglement times would increase, resulting in higher reflex impairment and thus higher mortality.

Possible solutions to mortality

Among all the variables we measured at the time of capture, the only one that was statistically linked to post-release mortality by our analyses was RAMP score; our multi-year data set supports a previous single-year study (Raby et al. 2012). The finding that variables other than reflex impairment were not associated with survival was surprising. This discrepancy may be largely explained by some of the mortality occurring as a result of factors unrelated to capture (e.g., natural mortality or tagging effects). It also suggests that the severity of capture stress experienced by an individual fish was influenced by aspects of capture that were not measured. Interestingly, while entanglement time did not show a direct statistical association with post-release mortality, it was correlated with RAMP scores, which have previously been shown to predict survival in Fraser River coho salmon (Raby et al. 2012). Although this is not a strong statistical relationship, we can advise that any capture or handling techniques that result in lower RAMP scores and more vigorous fish (e.g., reducing entanglement time) would be beneficial to minimizing post-release mortality.

The full suite of factors that led to reflex impairment may have not been identified by our study because a fish's RAMP score is likely to be reflective of its unique capture experience, such as its location within a net or the techniques used by the crew that catches it. We did not attempt to quantify such variables, and it would be very difficult to do so in an active fishery. We handled bycatch from 12 separate fishing crews during the study, and there were variations in how their nets were pulled into shore, how fish were crowded and sorted (Fig. 2), and slight gear differences (net material and mesh size). Some of the differences likely depended on variation in the local riverbank morphology (slope and substrate), the strength of the river current, the training and coordination of the crew, whether the crew used a truck to pull in their net, and the size of the catch in a given set. Very large hauls (>1000 fish) would almost always necessitate leaving the net in deeper water for sorting, thus suggesting that bycatch at least remained submerged and supplied with oxygen until it was located and released (Fig. 2B). However, overcrowding resulted in dissolved oxygen (DO) depletion to the extent that DO saturation decreased to 56–60% within 10 minutes of the start of sorting in one large set we measured (Fig. 2B). Approximately 30 minutes into the sorting process for that set, DO had further decreased to 50% saturation at the upstream end of the net, and to 36–40% at the downstream end. The effect of those changes in dissolved oxygen were visibly evident: the target species (pink salmon) at the upstream end of the net were alive, upright, and facing upstream, while at the downstream end all the catch appeared to be dead or moribund. In smaller, more typical net sets (Fig. 2A), the catch was brought into a similar water depth but more easily spread out along the shoreline, resulting in less crowding, although the fish were often in water shallow enough that half their gills were air exposed. In those sets it was easier to quickly identify and release coho salmon. In two such sets we monitored, oxygen only descended to ~75–80% saturation during the <20 minutes required to complete sorting, while in a third net set (e.g., Fig. 2A), DO saturation decreased to 42% 25 minutes into the sorting process (by which time all bycatch had been released). There were instances of crews pulling their entire catch completely onto the beach for sorting, air exposing both the target catch and bycatch (Fig. 2C). Though resulting in air exposure, this method always ensured coho salmon were identified and released very quickly, typically after 1–2 minutes of air exposure. Pulling the entire net onto shore was only physically possible with smaller sets of ~100–300 salmon, and often necessitated by a steep riverbed and strong current that made leaving the net in deeper water for sorting unsafe for the fishers (though this was not the case in Fig. 2C).

We found no evidence that the fish revival bag tested in this study benefited post-release survival. Coho salmon provided with a 30-minute recovery period in the flow-through fish bag (Fig. 3B) prior to release were no more likely to migrate successfully than fish immediately released after tagging. While fish were clearly invigorated by receiving 30 minutes of ram ventilation (i.e., forced water flow over the gills), the bag seemed to offer no added survival benefit for fish beyond that provided by a free-swimming recovery in the river. Physiological evidence has shown that a free-swimming recovery is the optimal way for salmonids to return to homeostasis following exhaustive exercise or fisheries capture (Milligan et al. 2000, Farrell et al. 2001). Thus, we suspect that facilitating revival using recovery bags only benefits those fish that are severely impaired (i.e., unable to swim), whereas it likely represents added chronic confinement stress for fish otherwise able to maintain equilibrium during the recovery period. Indeed, in the present study there was a small (non-significant) increase in survival associated with the recovery bag for fish with a negative orientation (equilibrium) reflex (47% survival with recovery bag treatment, 35% without, $N = 17$ fish per group). In general, facilitated revival techniques may be most useful in contexts where post-release predation occurs (Brownscombe et al. 2013, Raby et al. 2013); in the lower Fraser River where water turbidity is high there is little evidence that this is a major issue, as compared with the marine environment where revival techniques are currently in use for coho salmon (Farrell et al. 2001). It is possible that a shorter revival duration would have been more beneficial (e.g., 10–15 minutes) by allowing enough time to regain basic vitality without extended confinement stress. Other research has shown that various means of facilitating post-capture revival (including recovery bags) can be effective, but that attempts at revival can also be misguided in some contexts (Farrell et al. 2001, Brownscombe et al. 2013, Donaldson et al. 2013, Robinson et al. 2013, Nguyen et al. 2014). Future research on facilitating revival of fish bycatch should take the form of well-controlled experiments that examine what recovery durations and techniques are optimal and at what level of impairment fish benefit from revival.

Perspectives of the fishery participants

The most notable pattern in the results of the survey was the general willingness to engage in strategies to mitigate bycatch mortality. For example, the majority of aboriginal fishers were receptive to using the fish recovery bags (Fig. 7). The recreational angling community in the lower Fraser River were asked similar questions regarding fish recovery bags (Donaldson et al. 2013) and were less receptive (>40% negative responses) when asked, "What do you think of the idea of a revival bag?" Our biotelemetry data suggest that recovery bags may have limited potential for improving survival in the beach seine fishery. Nonetheless, responses on the recovery bag questions suggest there is a general likelihood that members of the fishery would embrace strategies that benefit coho salmon they catch. Though a plurality of respondents stated that beach seine capture does not affect survival of coho salmon, which conflicts somewhat with our findings, many were able to identify causes of stress and suggest ways to improve survival (Figs. 5 and 6). Even more encouragingly, there was a clear willingness to alter handling practices to improve the condition of bycatch, such as by leaving the net in deeper water for sorting to ensure adequate oxygen supply to bycatch until it is found. Collectively, the human dimensions data painted a picture of a fishing community that would be receptive to advice about how to best handle coho salmon to maximize their survival if the advice is supported with scientific evidence.

Integration and management recommendations

In the introductory text of DFO's selective fishing policy (DFO 2001), Thompson River coho salmon were cited as the lead example of a fish population whose restoration was being slowed because of bycatch in fisheries targeting other, more abundant Pacific salmon. Since the shift towards a selective fishing policy began in Canada's Pacific fisheries (DFO 2001), managers have applied a 5% mortality rate to coho salmon caught in the aboriginal beach seine fishery for the purpose of ensuring that overall bycatch mortality (all fisheries combined) is limited to a level that does not significantly compromise numbers of spawning adults. The bycatch mortality estimate in this paper is higher than the 5% currently applied. Based on our data, we recommend fisheries management consider the following options for updating the bycatch mortality rate used to manage this fishery: a minimum of 17% bycatch mortality (Fig. 4); a value based on 48-hour mortality (18.6%), or an estimate more reflective of total mortality (39%; Table 2). More work is needed to articulate the benefits and disadvantages of each approach. Unfortunately, comparable multi-year studies have not been done on all the other fisheries that bycatch interior Fraser coho salmon. Of the little work that has been done, beach seines have consistently resulted in the highest post-release survival relative to the other Fraser River fisheries that have been evaluated (i.e., higher than angling or gillnets [Buchanan et al. 2002, Donaldson et al. 2011, 2012, 2013, Nguyen et al. 2014]), which suits the management shift towards a selective fishing policy (DFO 2001). In fact, management and stakeholders can use this information to contemplate the possibility of an even greater shift towards gear types that minimize release mortality.

Beyond simply documenting the extent of the problem, we have attempted to identify solutions to potential causes of mortality. At this time we are unable to recommend use of fish recovery bags in the beach seine fishery. Encouragingly, however, many of the participants of the fishery were enthusiastic about the idea. Those responses suggest that fishers would be similarly enthusiastic about other means of improving survival of bycatch, perhaps including reducing entanglement time. Alternatively, fish bags could be used on a voluntary basis with a precaution that they only be used with severely impaired coho salmon, and whereby the fish only remains in the bag until reflex actions are regained. The expanded validation of the RAMP approach in the present study provides confirmation that this simple technique is ready for use in this fishery if needed (Raby et al. 2012). The observers in the fishery could easily be taught how to conduct RAMP assessments to monitor the condition of bycatch in real time, provide advice to their crews on how to improve fish condition, and make decisions about whether individual fish should be revived using recovery bags.

The key variable that was significantly associated with reflex impairment was entanglement time. Entanglement time was also positively correlated with total catch, with bycatch often being difficult to locate in larger sets, resulting in a wider range of entanglement times for those sets. To minimize reflex impairment and maximize survival, the fishers should be encouraged to: (a) make all efforts to release coho salmon to the river within 5 minutes of pulling the net into shore, and (b) particularly if the catch is large (e.g., >500 fish), minimize crowding by leaving the net in deeper water during sorting, so that bycatch are adequately supplied with oxygen until they can be located. In our surveys, we learned that many of the fishers understand the benefits of such practices, are willing to use them, and that some already do so. However, there is clear potential for (a) an increase in fisher awareness of best bycatch handling practices and (b) reductions in reflex impairment. Most of the participants in the fishery have intuition based on a lifetime of experience capturing and handling salmon (i.e., traditional ecological knowledge [Huntington 2000]) that could enable them to develop their own techniques that reduce reflex impairment. With observer-based collection of RAMP data, fisheries management would have the option to develop incentives that motivate the fishers to minimize RAMP scores (and thus mortality; a general approach used with success in tuna fisheries [Hall et al. 2000]).

Synthesis

This paper demonstrates that fisheries science, biotelemetry, and human dimensions surveys can be combined to evaluate a conservation problem for an endangered population of salmon and inform resource managers and users. We consider this a model approach for conservation research, because it can help address the persistent challenge of generating science that "bridges the knowledge–action boundary" (Cook et al. 2013). A well-known barrier to transitioning from scientific knowledge to conservation action is the scientific structure that values publications and grant income, but not engagement with stakeholders (Cook et al. 2013). As part of broader stakeholder meetings regularly held to present findings from several projects by our research group (see Cooke et al. 2012), we disseminated the findings of this study throughout the course of data collection and received input for following phases of research. Collaboration with stakeholders was done to increase the likelihood that findings are subsequently adapted. In fact, this study was initiated by conversations with fisheries managers that followed a 2009 stakeholder meeting, and was only possible with various forms of support from the resource users, government, and environmental NGOs (among others). Based on the experience with this study, adding a human dimensions component to conservation research represents good value considering the modest time investment required (e.g., conducting the surveys required ~8 days for two researchers). Previous research has shown the utility of such an approach for Fraser River sockeye salmon recreational fisheries (Donaldson et al. 2013). Other papers have shown the value of combining sociology and natural sciences to address animal conservation issues (African elephants, *Loxodonta Africana* [Guerbois et al. 2012]; red deer [Irvine et al. 2009]). In the conservation of tropical forests subject to logging, a conservation context somewhat analogous to harvest fisheries, this approach has been applied numerous times (Lele and Kurien 2011 and references therein). Fisheries bycatch is recognized widely as a leading global threat to biodiversity (Gray 1997, Kappel 2005, Davies et al. 2009), towards which a great deal of ecological knowledge and research have been applied (Hall et al. 2000, Soykan et al. 2008). Our effort is among the first integrative research papers in the realm of fisheries bycatch, and certainly the first for a freshwater bycatch issue (Raby et al. 2011). In addition to helping address a conservation issue for an endangered population of salmon, we hope this paper can have value for future interdisciplinary research in aquatic conservation.

Acknowledgments

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Supplemental Material

Appendix

Additional methods detail on coding human dimensions survey responses (*Ecological Archives* A024-207-A1).

Supplement

Data for all 295 coho salmon bycatch handled in the study (*Ecological Archives* A024-207-S1).